The 2201 Hydroelectric

A new system and strategy fo

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Vibration monitoring is helping hydroelectric plant personnel increase machine availability and plant productivity. However, many of the monitoring systems in use were not designed for low speed, hydroelectric machines. Bently Nevada's ongoing research of common hydroelectric machine problems has resulted in new strategies for detecting them. We used this knowledge to design a monitoring system specifically for hydroelectric machines, a system that extracts the information that makes these new strategies possible. Our new 2201 Hydroelectric Vibration Monitoring System is the key to efficient hydroelectric machine management.

Simplified hydroelectric turbine operation

Water from the dam, called *head water*, passes through a *penstock*. The penstock is a (usually steel-lined) pipe or conduit that carries water into the *scroll case*. The scroll case directs the water through fixed guide vanes, to the *wicket gates*. Wicket gates are variable guide vanes that adjust the flow of water through the turbine, controlling its speed and power. After passing the wicket gates, the water passes through the rotating part of the turbine, the *turbine runner*. The water spins the turbine runner, the turbine shaft and the generator connected to it. Water discharged from the turbine, called *tail water*, is carried downstream, through the *draft tube*.

2201 Hydroelectric Vibration Monitoring System

Many large, slow rotating, vertical machines are now monitored by continuous, online vibration monitoring equipment. However, these monitoring systems were originally designed for high speed, critical machines. Typically, machines in a hydroelectric plant rotate at 60 to 600 rpm; a monitor designed for high speed machines may not detect some problems on slower speed machines. Bently Nevada developed a new hydroelectric monitoring system to help solve this business problem. Our solution is the 2201 Hydroelectric Vibration Monitoring System. This fully-integrated system consists of:

- A 2201/06 Low Speed Machine Monitor
- An Allen-Bradley 1771 chassis and power supply
- An Allen-Bradley Programmable Logic Controller (PLC®)
- A personal computer and our HydroVU™ display software

The 2201/06 Low Speed Machine Monitor measures peak to peak shaft displacement at speeds as low as 15 rpm. The 2201/06 Low Speed Machine Monitor and 2201 System interface with the Allen-Bradley PLC5® family of controllers.

Bently Nevada's HydroVU Software runs on a personal computer. It displays current vibration amplitudes and trends, current monitor configuration and alarm setpoints. From your personal computer, you can configure the 2201 Hydroelectric Vibration Monitoring System and set alarm levels.

The 2201 Low Speed Machine Monitor uses proximity probe signals for its inputs. As a source of vibration data, Bently Nevada noncontacting proximity probes are ideally suited for hydroelectric machines. A proximity probe is

Vibration Monitoring System:
managing vertical hydroelectric machines

the only transducer that measures shaft motion and position directly, and it has a low frequency response that is ideal for monitoring low speed machines.

Common hydroelectric machine problems

Before we developed our hydroelectric monitoring system, we set out to understand common hydroelectric machine faults. Bently Nevada engineers talked with hydropower station personnel, engineers, consultants, machinery manufacturers and industry experts worldwide. We collected vibration data from instrumented hydroelectric machines and performed tests to determine which common problems could be detected through shaft-relative displacement measurements. We found that proximity probe measurements could identify these problems:

- Rough Load Zone
- Shear pin failure
- Mechanical unbalance
- Electrical unbalance
- Hydraulic problems (turbine)
- Misalignment
- Increased bearing clearance

Detecting hydroelectric machine problems

Rough load zone

The Rough Load Zone is an operational phenomenon known as Rheingans Influence; it is a machine operating load range where vibration is excessive. It is a common occurrence with Francis turbines, and is caused by flow disturbances downstream of the turbine runner. Machines should not be operated continuously in this region.

Typically, Rough Load Zone occurs when the wicket gates are 30% to 50% open. The zone varies from machine to machine, and also as a function of head and tail water levels. Therefore, the zone can move, depending on the turbine's current operating parameters. To avoid running in the Rough Load Zone, operators are usually restricted to certain fixed operating regions.

Subsynchronous vibration is the Rough Load Zone's main vibration characteristic, although higher-order harmonics, such as 2X and 3X, occasionally occur. Sometimes, synchronous (1X) vibration displacement actually decreases.

Figure 3 shows data from a typical Francis turbine as it passed through the Rough Load Zone. The waterfall plot shows displacement spectra sampled as load increased over time. Notice that 1X displacement amplitude varied only slightly as load increased. However, subsynchronous vibration became very evident at low load, and subsided as the load increased.

This typical response suggests that the Rough Load Zone can be identified by an increase in "Not 1X" vibration (vibration that is not synchronous with running speed). The 2201/06 Low Speed Machine Monitor can measure Not 1X vibration and generate an alarm when it exceeds a preset level. The 2201/06 can alert plant operators when Not 1X vibration increases, so they can adjust operation away from the Rough Load Zone. Instead of running all machines within a fixed load range, operators can run each machine within a different load range, to maximize productivity and plant efficiency.

Shear pin failure

Water flows through wicket gates prior to entering the turbine runner. The wicket gates act as inlet guide vanes, and are adjusted to meet load requirements. Each is supported by an upper and a lower bearing and is connected to a common control ring via a shear pin. The control ring, which synchronizes the movement of all the wicket gates, is moved by a governor-controlled hydraulic ram. The shear pins are a weak link, designed to fail if a wicket gate seizes, limiting damage. However, shear pins can also fail in service, usually because of fatigue.

When a shear pin fails, the machine's response changes in two ways that we can measure with proximity probes. Both are due to a pressure differential region created when the free gate takes a neutral position in the water flow.

The first change we can measure is increased nX vibration, which is vibration at an integer multiple of running speed (n is the number of turbine blades and X is the machine's rotative speed).

The pressure differential created by the free gate imparts a force on the turbine runner each time a blade passes the region. This causes the nX vibration component, which can be significant. However, while nX vibration may increase, overall vibration may increase only slightly, because at the same time 1X vibration may decrease.

1X vibration may decrease because of the second change we can measure, a change in shaft average centerline position. The shaft average centerline position is the position about which the shaft vibrates within its bearing clearance.

The pressure change caused by the free gate moves the shaft within its bearings, usually toward the failed gate. Its movement can produce a significant bearing load, which can damage bearings, and reduce 1X vibration, due to the increase in system stiffness.

A machine with a failed shear pin should not be operated for long. However, the failure may go unnoticed by the operators, because overall vibration may not change enough to trigger an overall vibration amplitude alarm.

As a test, a wicket gate shear pin was removed from a Francis turbine prior to startup. We plotted the turbine shaft average centerline position as the machine load was increased and then decreased (Figure 4). As the machine ran up to operating speed, water flow moved the uncontrolled wicket gate into a position similar to that of the controlled gates. During this time, there was no noticeable change in vibration amplitude. As the load was increased, however, the free gate did not follow the controlled gates. The turbine runner moved toward a low pressure region formed near the free gate.

The removed shear pin was located 38° left, from the top of Figure 4; the plot shows that the shaft centerline moved toward the uncontrolled gate. If shear pin failure occurred when the machine was operating on load, the movement would have been sudden and could have damaged the bearing. Bearing pad temperature monitoring might have detected an increase in bearing load, but if not all the bearing pads were monitored, a failure could go undetected.

With the 2201 Hydroelectric Vibration Monitoring System, the nX vector and shaft average centerline position alarms are "and" voted to provide a shear pin failure alarm. This is an alert alarm only, and should not be set to automatically shut down the turbine, as this could cause further damage. If shear pin failure occurs, the machine must be shut down in a controlled manner, so the water flow can help close the free gate.

Mechanical and electrical unbalance

The balance condition of a rotor can be determined by measuring the 1X vector (amplitude and phase), and by noting its response as the machine runs through its speed and load range.

When machines are commissioned, either after major inspections or when new, the vibration data is recorded at predetermined steady state conditions. The conditions may be certain speeds during startup or certain loads when synchronized. During commissioning, it is possible to document the machine's mechanical and electrical responses. A mechanical unbalance will not change with load; however, a machine's vibration response does change with load if the vibration is due to unbalanced electrical fields or thermal effects.

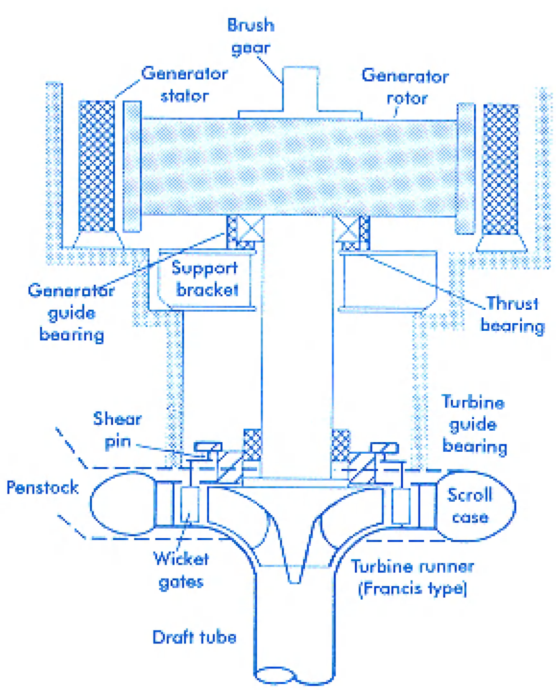

Figure 1
Two bearing machine, Francis turbine

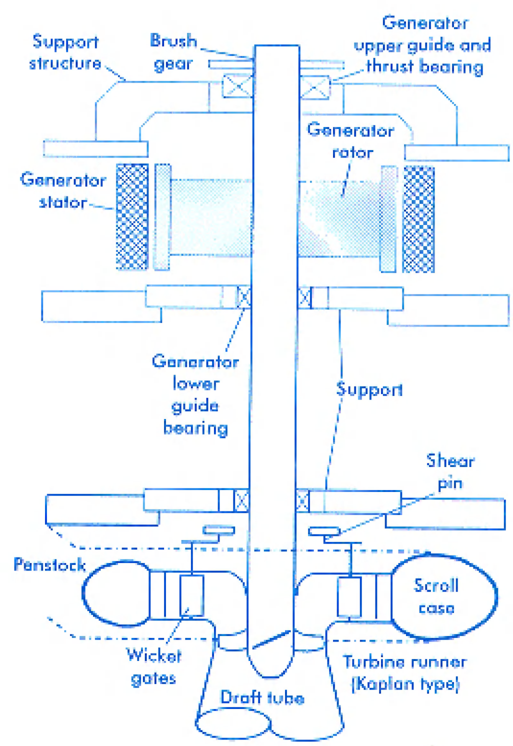

Figure 2
Three bearing machine, Kaplan turbine

The 2201/06 makes it easy to monitor changes in mechanical and electrical balance, with "Acceptance Regions." An Acceptance Region is trend information, of 1X or 2X vibration vectors, or the shaft average centerline position. The user defines the Acceptance Region for each shaft radial vibration or position measurement on the machine, based on its normal performance. With the 2201/06, you can set alarm setpoints for maximum and minimum values of both amplitude and phase.

Vertical misalignment and thrust bearing wear

The thrust position is the vertical position of the shaft thrust collar relative to the thrust bearing. It is an important measurement in vertical hydroelectric turbines, because in these machines, the whole weight of the rotor is supported by the thrust bearing. A thrust position that changes with load can indicate vertical misalignment of the turbine runner relative to the wicket gates. The thrust position can change if the misalignment causes pressure fluctuations under the turbine runner that lift the rotor.

Thrust position also changes slowly over time, as the thrust bearing wears. Thrust bearing wear is most easily seen by trending thrust position over time.

The 2201/06 Low Speed Machine Monitor measures thrust position. It can indicate thrust bearing wear and vertical misalignment of the turbine runner relative to the wicket gates.

One monitor for all hydroelectric machine measurements

Hydroelectric machines have unique problems that require a special monitoring strategy. Direct vibration and 1X vector monitoring are extremely useful, however, other measurements are essential for detecting problems at an early stage of development. The 2201 Hydroelectric Vibration Monitoring System combines these measurements, with individual full-scale ranges and alarms, in a single, four-channel monitor. The 2201 Hydroelectric Monitoring System measures all of the important hydroelectric machine vibration parameters:

- Overall (direct) vibration amplitude
- 1X vibration amplitude and phase (1X Vector)
- nX vibration amplitude and phase (nX Vector)
- "Not 1X" vibration amplitude
- Shaft average centerline position
- Thrust position
- Gap

For the larger displacements of hydroelectric machines, the 2201/06 Monitor has user-selectable full scale ranges up to 2500μm pp. Each monitor channel and parameter has individual alarm setpoints and variable alarm time delays. These help you avoid nuisance alarms when transient high-amplitude vibration occurs.

The innovative 2201 Hydroelectric Vibration Monitoring System helps Maintenance and Operations personnel optimize hydroelectric plant operation. For more information on this new monitoring system, contact your nearest Bently Nevada sales and service representative.

Reference:

1. Vladislavlev, L.A., "Vibration of Hydroelectric Units in Hydroelectric Power Plants," American Publishing Co. PVT. LTD., New Delhi, 1979.

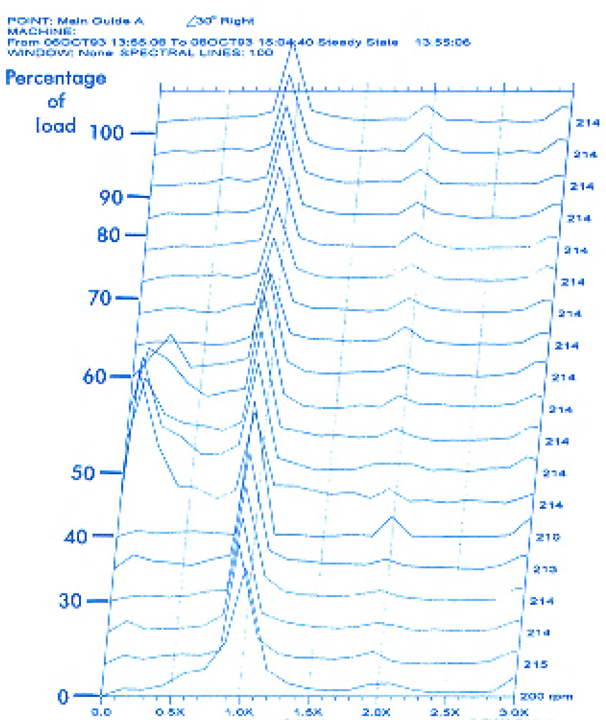

Figure 3
Waterfall spectrum plot showing Rough Load Zone

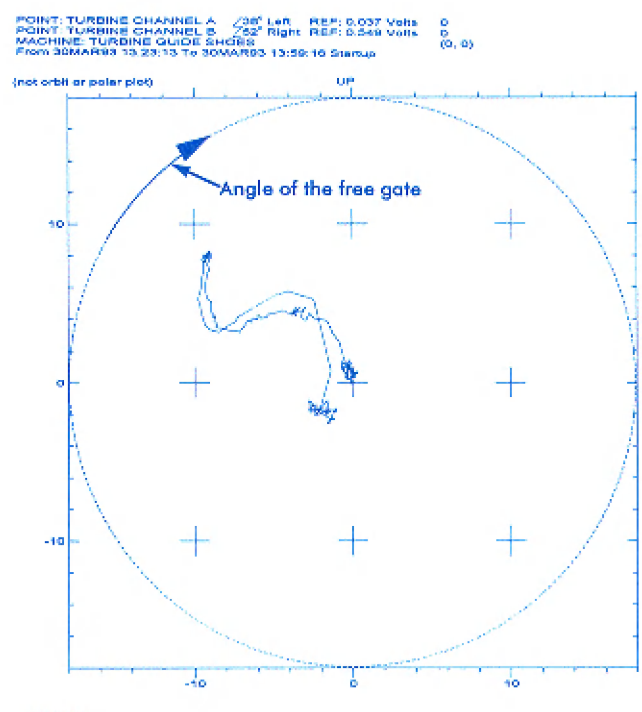

Figure 4
Shaft centerline position, sampled with shear pin removed. The load was increased and then decreased.